Feasibility study of the use of rapid manufacturing technology in a new Unmanned Aerial Vehicle design

June, 27th 2014

AUTHOR: Jonatan Domènech i Arboleda

DIRECTOR: Pau Nualart Nieto
Co-DIRECTOR: Dra. Jasmina Casals Terré

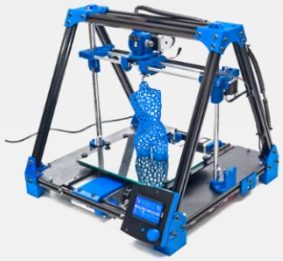
A dissertation submitted to the Department of Manufacturing Technology ETSEIAT Universitat Politècnica de Catalunya

In partial fulfilment of the requirements for the Bachelor's degree in Aerospace Vehicles Engineering

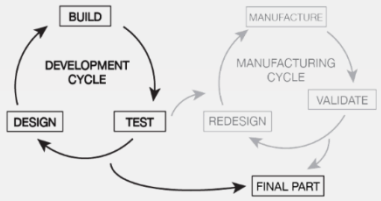
Rapid manufacturing system [RMS]

FUNDACIÓ cim UPC BARCELONATECH

Feature	Value	Units
MODEL	RepRap BCN 3D+	
MANUFACTURER	Fundació CIM	
PATENTS	Open Source	
COST	740	€
MAX. SPEED	200	mm/s
MIN. PRINT LAYER HEIGHT	0,1	mm
PRINT TOLERANCE	0,05	mm
MAX BUILT HEIGHT	200	mm
MAX BUILT WIGHT	210	mm
MAX BUILT LENGTH	240	mm
NOZZLE DIAMETER	0,4	mm
FILAMENT	ABS-PLA-NYLON	



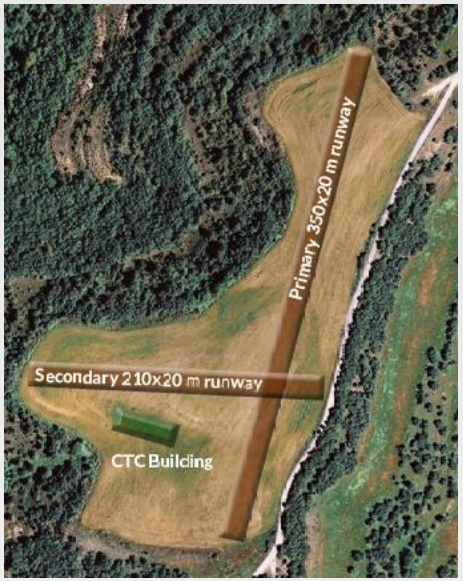
RepRap BCN 3D+



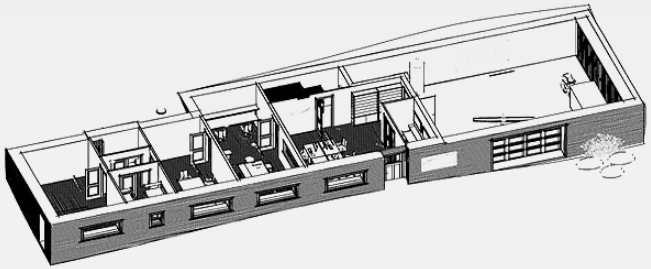
RMS cycle

Unmanned Aerial Vehicle [UAV]

CAT UAV



TSA 31 CTC-MOIÀ



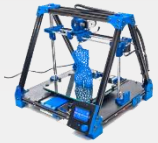
NEW BIOCLIMATIC HANGAR

STATE OF THE ART





UAV		SULSA	WENDY	VAST AUAV	AMRC	EASY STAR II	BARCELONA
Year		2011	2012	2013	2014	2012	2014
Design		SOUTHAMPTON	VIRGINIA	MIT	SHEFFIELD	MULTIPLEX	ETSEIAT
Sponsor		3T RPD	STRATASYS	US AIR FORCE RAPID 3D IMAGING	BOEING		
Manufacturing System		FDM	FDM	FDM	FDM	Elapor® HD Foam	FDM
Weight	[g]	3000	-	3175	2000	720	
Wingspan	[mm]	1200	1981	1400 - 2000	1500	1385	1500



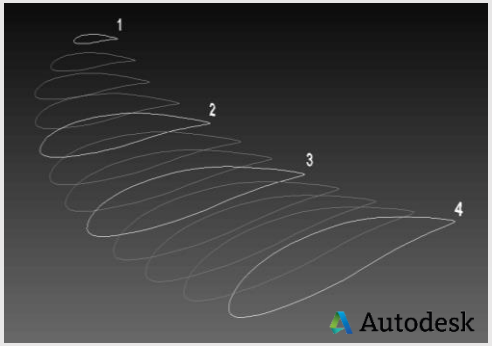
3D PRINTING	Material	3d printing	Tensile test	Linear Model	Methodology	Result	Conclusions	3/20
BARCELONA UAV	Concept	Wing 3DP & UL tests	Tail	Fuselage	Assembly			

3D PRINTING MATERIAL

	Recyclability	Tg [ºC]	Density [g/cm^3]	UTS [MPa]
ABS	Thermo polymer	105	1,06	44,8
PLA	**Biodegradable**	**65**	**1,23**	**57,8**
NYLON 6	Polyamide	58	1,20	70,0

Background source: http://www.inspirationgreen.com

CAx technologies



Airfoil DATA: **vertical alignment**

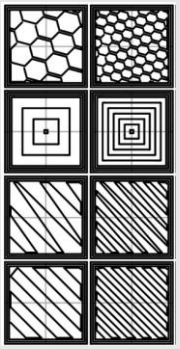
STL file

Volume:	263.1838 cm³	Area:	553.8010 cm²
Points:	1862	Edges:	5580
Triangles:	3720	Shells:	1
Holes:	0	Bad edges:	0
Boundary edges:	0	Boundary Length:	0.00 mm
Flipped triangles:	0		
Surface is closed:			Yes
Surface is orientable:			Yes

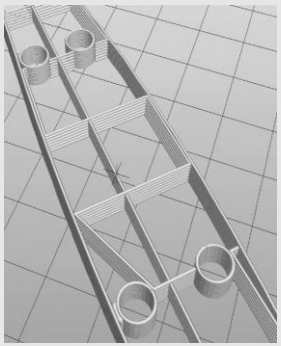
	Min:	Max:	Ø:	Dev:
Edges/Point	4.00	15.00	5.99	0.73
Triangles/Edge	2.00	2.00	2.00	0.00
Triangle Quality	0.00	0.80	0.20	0.16
Edge Length	0.11	116.13	11.72	8.51

STL exportation **100 µm precision**

Infill 20-40%

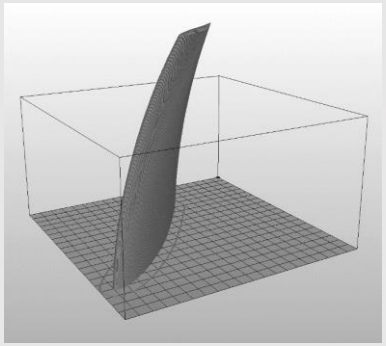


SLICER

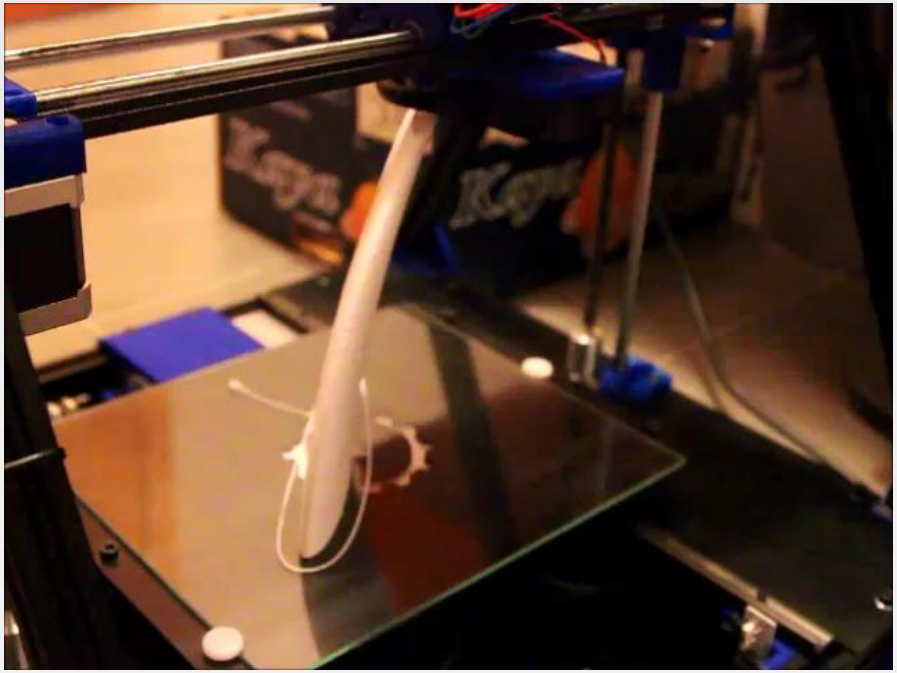


SLIC3r open source software

G-CODE



FIRMWARE

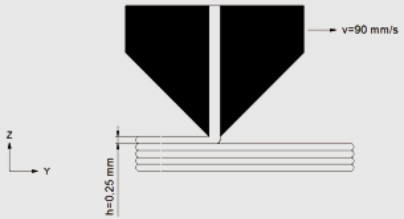


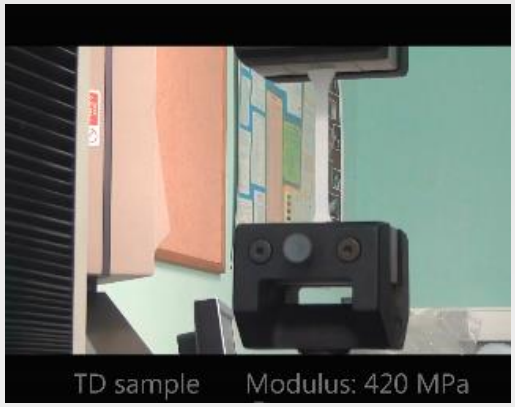
3D printing video

Part	Winglet 1
Date	01/04/2014
Software	Slic3e 9.10b
Layer height	0,25
Perimeters	1
Top solid layers	2
Bottom solid layers	1
Fill density	0,04
Perimeter speed	90
Infill speed	60
Travel speed	200

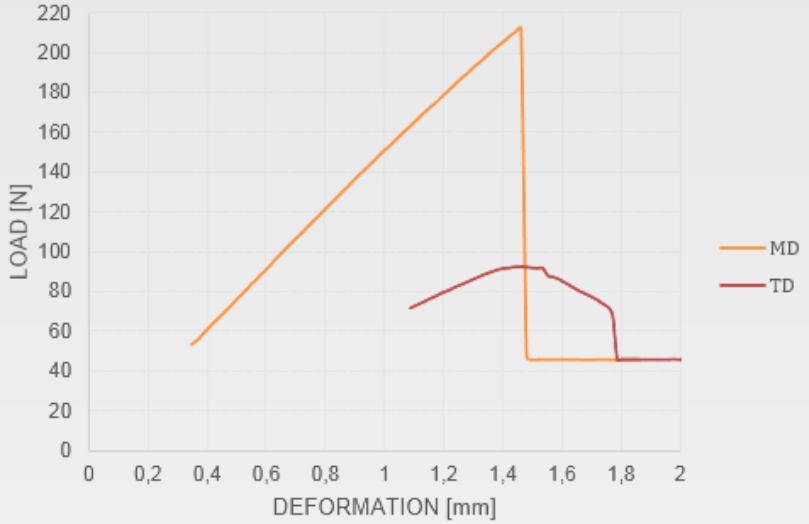
WINGLET 1	
Printing time	5h 2m 43s
Filament used	6302,3mm
Material volume	42,2 cm3
Part volume	263,2 cm3
Specific material volume	0,161
Material & Energy Cost	2,11 €

PLA TENSILE TEST





ETSEIAT MATERIALS LAB VIDEO



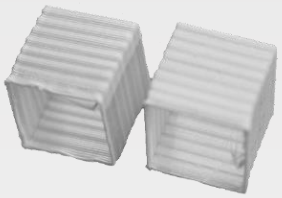
	width	Thickness	Maximum load	Maximum tensile	Modulus
Units	[mm]	[mm]	[N]	[MPa]	[MPa]
MD	10	0,8	212,297	26,5	**968**
TD	10	0,8	92,599	11,6	**420**

ANISOTROPIC 3D PRINTED PARTS

LINEAR MODEL APROXIMATION

Y: weight [g] X1: Z axis height [mm] X2: Speed [mm/s]

$X_1 \setminus X_2$	60		80		90	
0.25	0,20	0,20	0,19	0,20	0,19	0,19
0.20	0,20	0,21	0,20	0,20	0,19	0,20
0.10	0,21	0,21	0,20	0,21	0,20	0,20

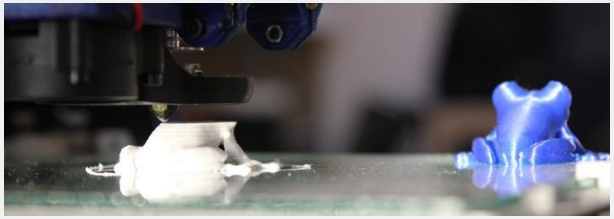


Translucent 3d printed PLA

$$Y = \begin{pmatrix} 0{,}20 \\ 0{,}20 \\ 0{,}19 \\ 0{,}20 \\ 0{,}19 \\ 0{,}19 \\ 0{,}20 \\ 0{,}21 \\ 0{,}20 \\ 0{,}20 \\ 0{,}19 \\ 0{,}20 \\ 0{,}21 \\ 0{,}21 \\ 0{,}20 \\ 0{,}21 \\ 0{,}20 \\ 0{,}20 \end{pmatrix} \quad X = \begin{pmatrix} 1 & 0.25 & 60 & 15 & 0.0625 & 3600 \\ 1 & 0.25 & 60 & 15 & 0.0625 & 3600 \\ 1 & 0.25 & 80 & 20 & 0.0625 & 6400 \\ 1 & 0.25 & 80 & 20 & 0.0625 & 6400 \\ 1 & 0.25 & 90 & 22.5 & 0.0625 & 8100 \\ 1 & 0.25 & 90 & 22.5 & 0.0625 & 8100 \\ 1 & 0.2 & 60 & 12 & 0.04 & 3600 \\ 1 & 0.2 & 60 & 12 & 0.04 & 3600 \\ 1 & 0.2 & 80 & 16 & 0.04 & 6400 \\ 1 & 0.2 & 80 & 16 & 0.04 & 6400 \\ 1 & 0.2 & 90 & 18 & 0.04 & 8100 \\ 1 & 0.2 & 90 & 18 & 0.04 & 8100 \\ 1 & 0.1 & 60 & 6 & 0.01 & 3600 \\ 1 & 0.1 & 60 & 6 & 0.01 & 3600 \\ 1 & 0.1 & 80 & 8 & 0.01 & 6400 \\ 1 & 0.1 & 80 & 8 & 0.01 & 6400 \\ 1 & 0.1 & 90 & 9 & 0.01 & 8100 \\ 1 & 0.1 & 90 & 9 & 0.01 & 8100 \end{pmatrix} \quad \hat{\beta} = \begin{pmatrix} \hat{\beta}_0 \\ \hat{\beta}_1 \\ \hat{\beta}_2 \\ \hat{\beta}_{12} \\ \hat{\beta}_{11} \\ \hat{\beta}_{22} \end{pmatrix} \quad e = \begin{pmatrix} e_1 \\ e_2 \\ e_3 \\ e_4 \\ e_5 \\ e_6 \\ e_7 \\ e_8 \\ e_9 \\ e_{10} \\ e_{11} \\ e_{12} \\ e_{13} \\ e_{14} \\ e_{15} \\ e_{16} \\ e_{17} \\ e_{18} \end{pmatrix}$$

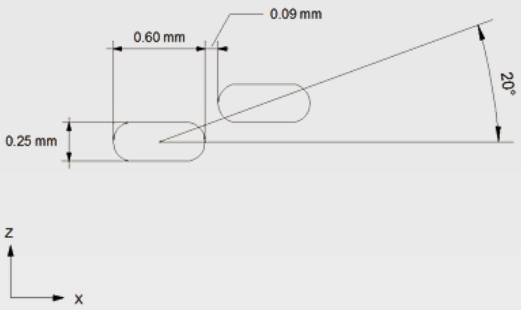
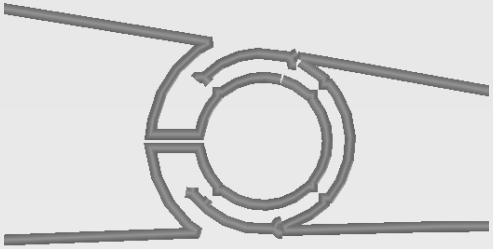
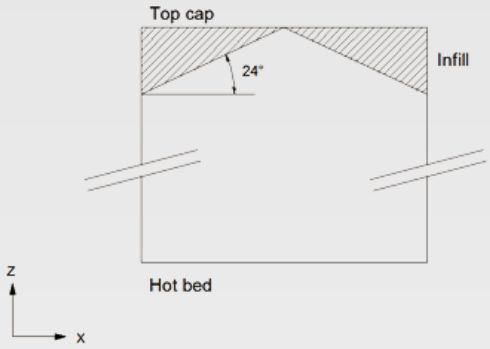
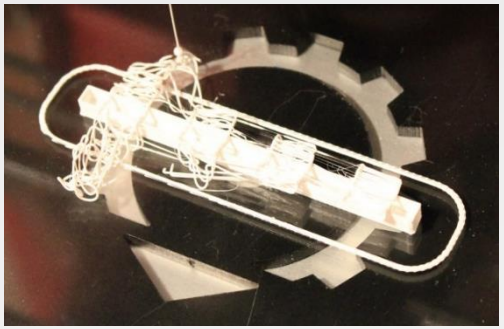
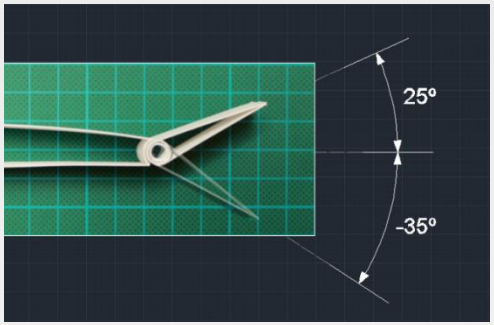
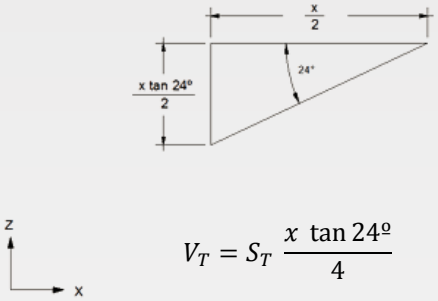
$$\hat{Y} = 0.2279 + 0.0493\, X_1 - 0.0003 X_2 - 0.00006\, X_1 X_2 - 0.3316 {X_1}^2$$

$$\hat{\boldsymbol{Y}} = 0.207093 - 0.18918 {\boldsymbol{X}_1}^2$$

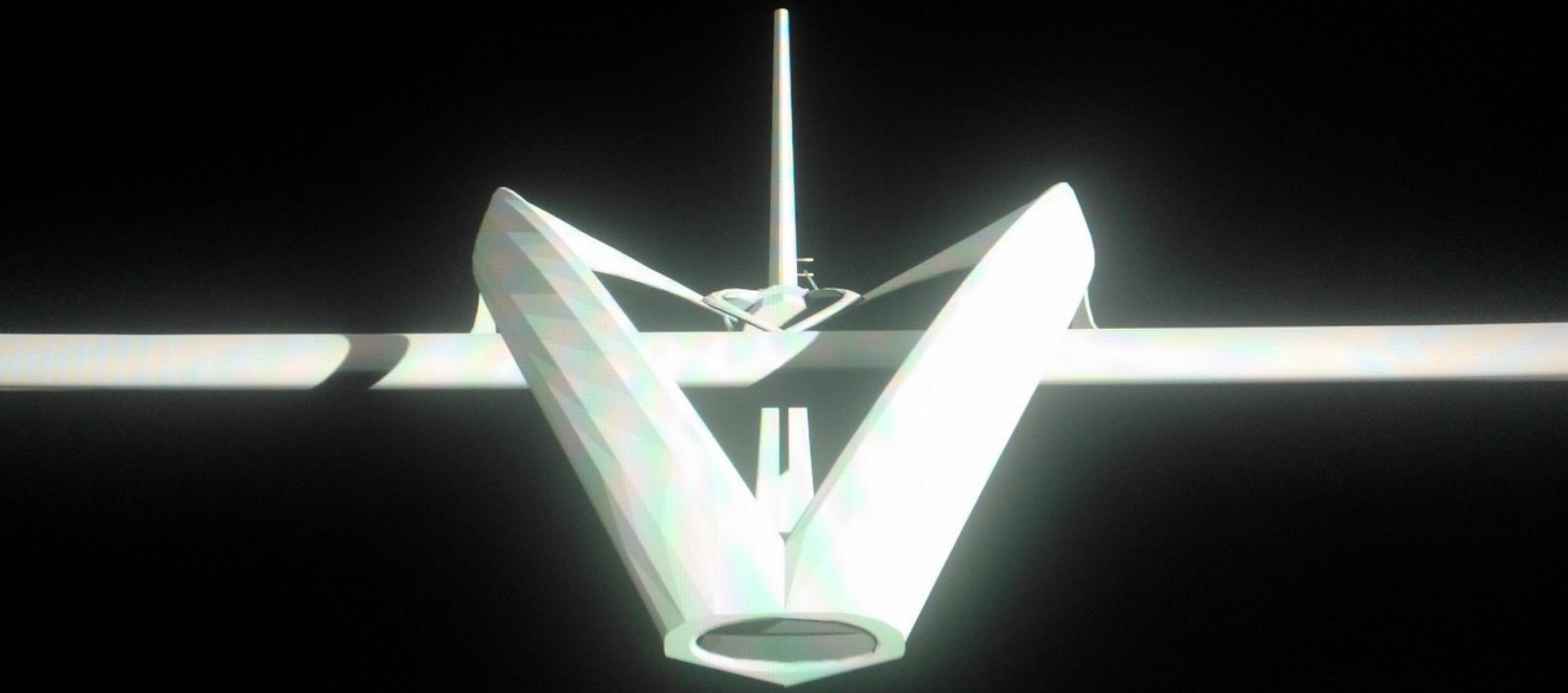


6.18 g ± 11.42%

3D PRINTING DESIGN

TREE METHOD	CLICK METHOD	CHEDDAR METHOD
		
		 $V_T = S_T \frac{x \tan 24º}{4}$
20º minimum angle with bed (24º SF)	Weak supports for mobile parts	93.3% reduction versus support mat. 83.4% reduction versus 40% Infill

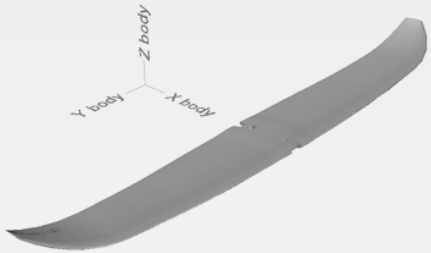
BARCELONA UAV CONCEPT DESIGN



3D printing tech PLA material 15dm wingspan 11dm fuselage length Less than 2000 g weight Payload Low cost Maximum 120 m FL

3D PRINTING	Material	3d printing	Tensile test	Linear Model	Methodology	Result	Conclusions	9/20
BARCELONA UAV	Concept	Wing 3DP & UL tests	Tail	Fuselage	Assembly			

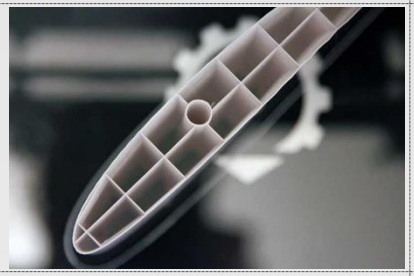
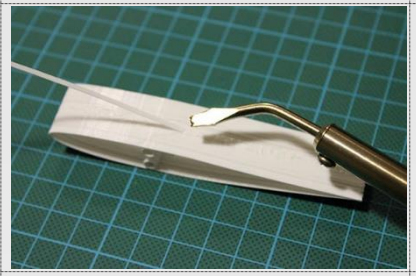
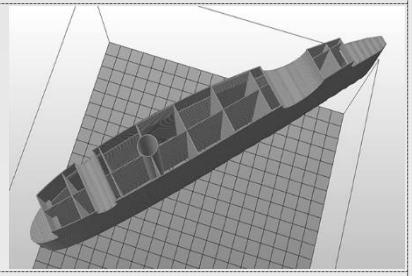
MAIN WING		
Parameter	Symbol	Value
Wing area	S_W	25.2 dm2
Wing position		High wing
Airfoil (similar)		NACA 2412
Aspect ratio	AR	8.93
Taper ratio	λ	0.3

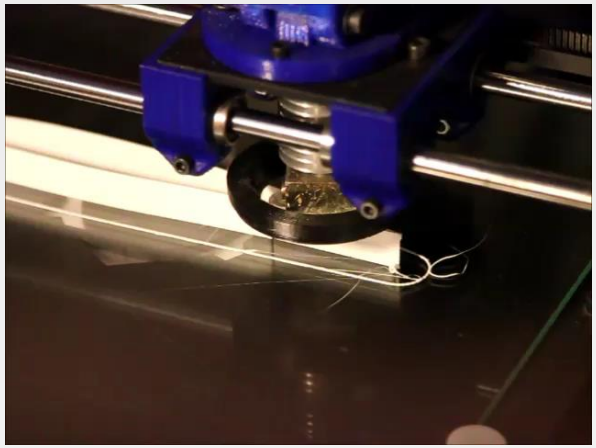


Tip chord	C_t	0.6dm
Root chord	C_r	2dm
Mean Chord	MAC	1.68dm
Span	b	15dm
Twist angle	α_t	2.75º
Sweep angle	Λ	7º
Dihedral angle	Γ	2º
Incidence angle	i_w	3º

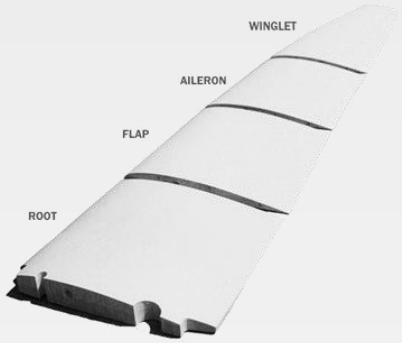
3D PRINTING	Material	3d printing	PLA Tensile test	Linear Model	Methodology	Result	Conclusions
BARCELONA UAV	Concept	Wing 3DP & UL tests	Tail	Fuselage	Assembly		

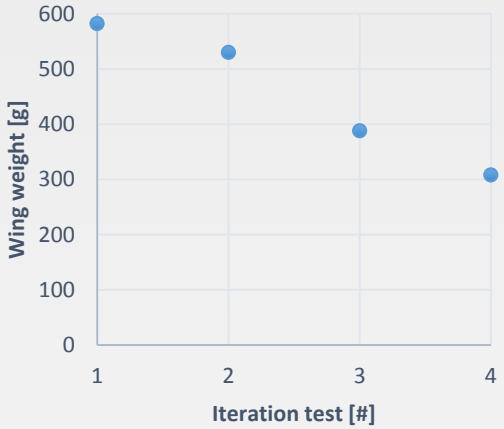
3D PRINTED WING

VERSION	1st	2nd	3rd	4th
FOCUS	Feasibility of 3D printing technology for aerodynamic shape requirements.	Infill orientation parameters.	Develop a fast and lightweight union methodology.	G-Code programming parameters
				
WEIGHT	582 g	529 g	386 g	305 g
REDUCTION	Reference	8 %	34 %	48 %



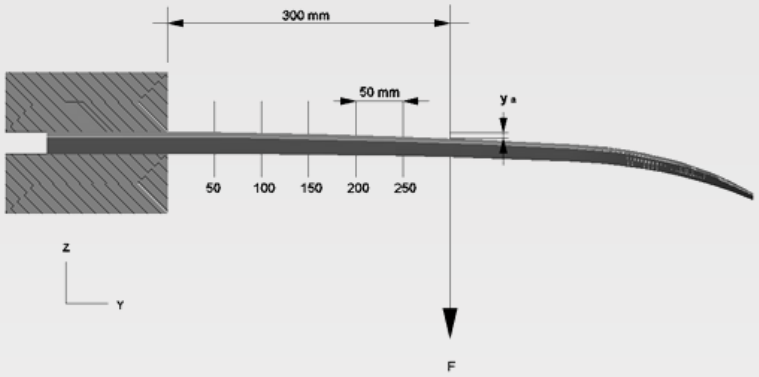
Aileron 3D printing process VIDEO



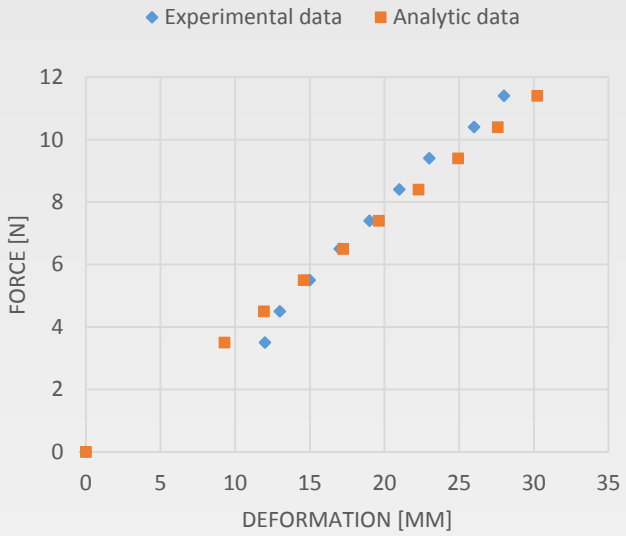


ULTIMATE LOAD TEST

Factor	Unit	1st	2nd	3rd	4th	5th	6th	7th	8th	9th
Weight	g	359.24	459.24	559.24	659.24	759.24	859.24	959.24	1059.24	1159.24
Force	N	3.5	4.5	5.5	6.5	7.4	8.4	9.4	10.4	11.4
Deformation	mm	12	13	15	17	19	21	23	26	28



$$ya = -\frac{F}{EI}\left(\frac{L^3}{2} - \frac{L^3}{6}\right) = -\frac{FL^3}{3EI}$$



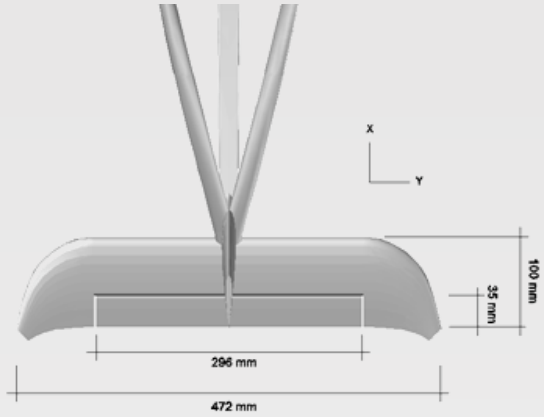
ETSEIAT LABORATORY VIDEO

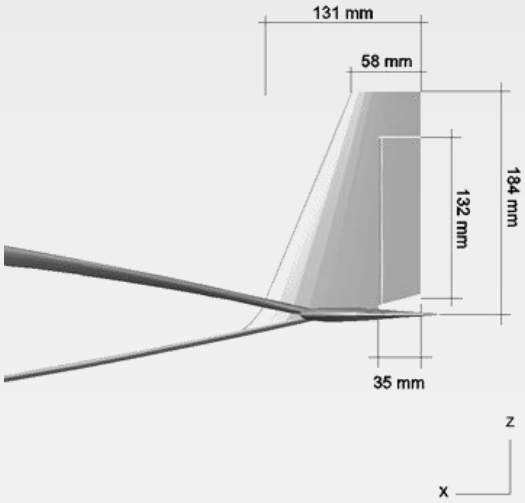
E (ExpData) = 550 MPa E (TD) = 420 MPa

Wing is made by different parts welded
Infill has been designed by printing 50% of layers.

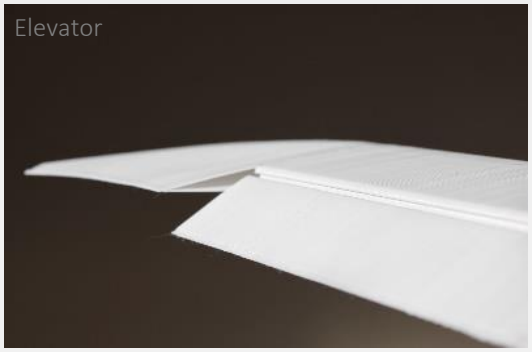
TAIL

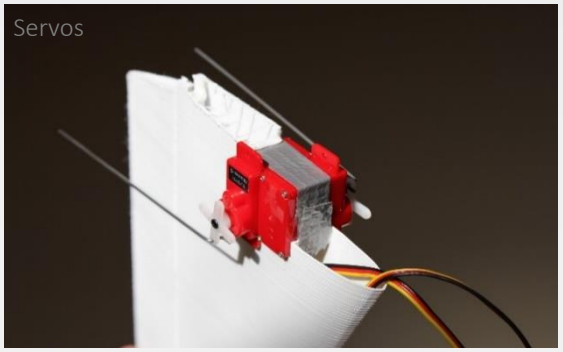
HORITZONTAL TAIL		
V_h	0.6	
L_h	5.84	dm
S h	4.5	dm^2
S h / S	0.17	
Airfoil	WORTMANN FX 76-120	
i_h	0	
AR_h	4.5	
Taper ratio	1	
Sweep angle	0	º
Dihedral Angle	0	º
b_h	4.72	dm
C_r	1	dm
C_t	1	dm
ELEVATOR		
S_e / S_h	0.24	
C_e / C_h	0.35	
b_e / b_h	0.64	
δ_e +	25	º
δ_e -	30	º





VERTICAL TAIL		
V_v	0.03	
L_{vt}	5.84	dm
S v	1.8	dm^2
S v / S	0.07	
Airfoil	WORTMANN FX 76-120	
i_h	0	
AR_h	1.95	
Taper ratio	0.45	
Sweep angle	15	º
Dihedral Angle	0	º
b_h	1.84	dm
C_r	1.31	dm
C_t	0.58	dm
RUDDER		
S_r / S_v	0.26	
C_v / C_v	0.37	
b_r / b_v	0.71	
δ_r +	25	º
δ_r -	25	º





NEW FUSELAGE CONCEPT DESIGN

70% fuse area reduction
versus standard shape

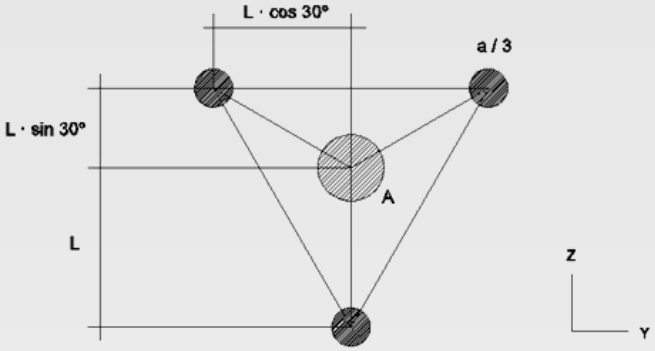
$$0.3\ A = a$$

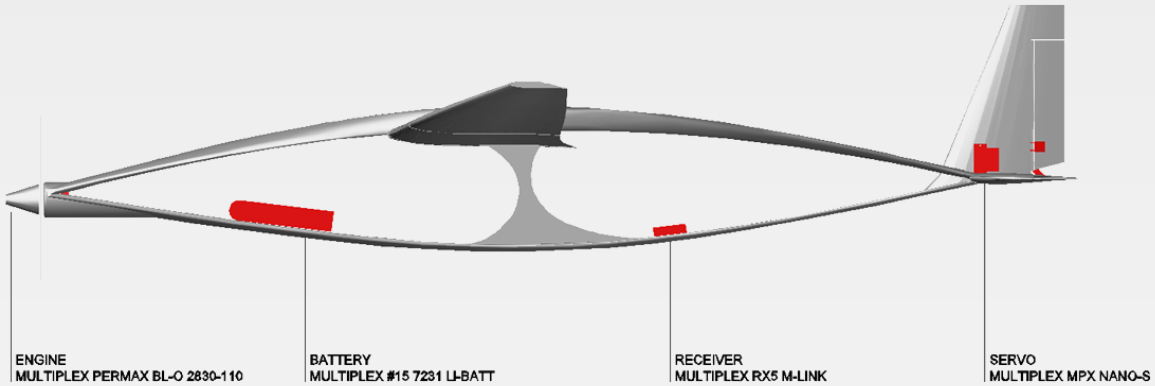
$$I_Y = \iint_A z^2\, dydz$$

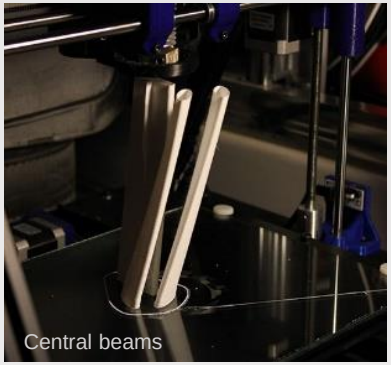
$$I_Y = I_{Y'} + Ad_z^2$$

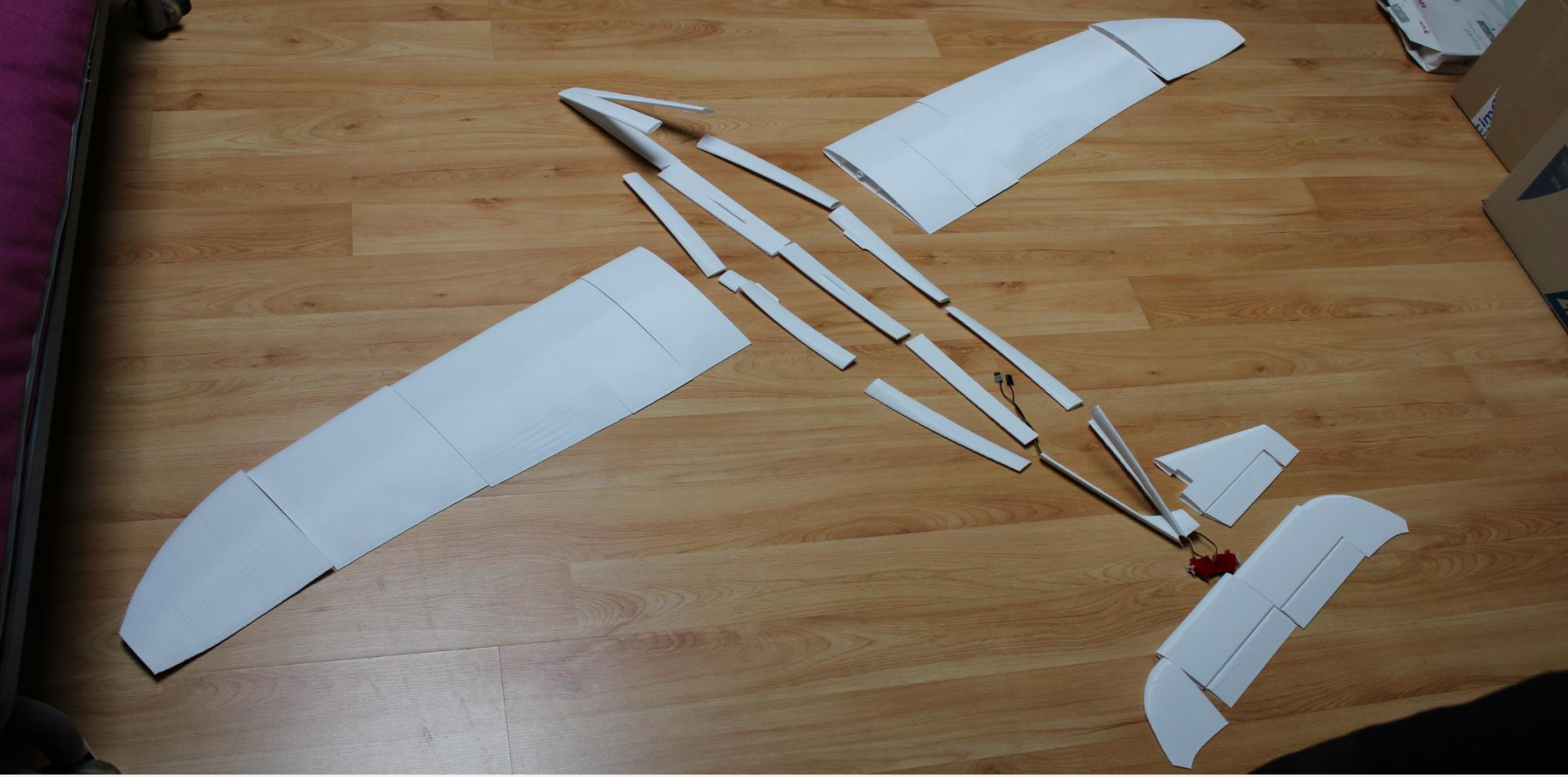
$$L = \sqrt{\frac{2 \cdot 10^4}{3\pi\ R^4}} = 85mm$$

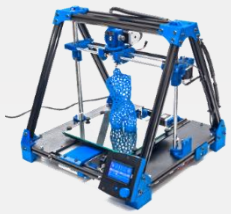
LU= 89.25 mm (5%SF)



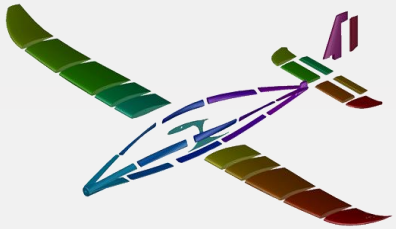


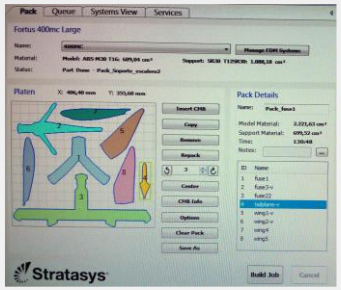






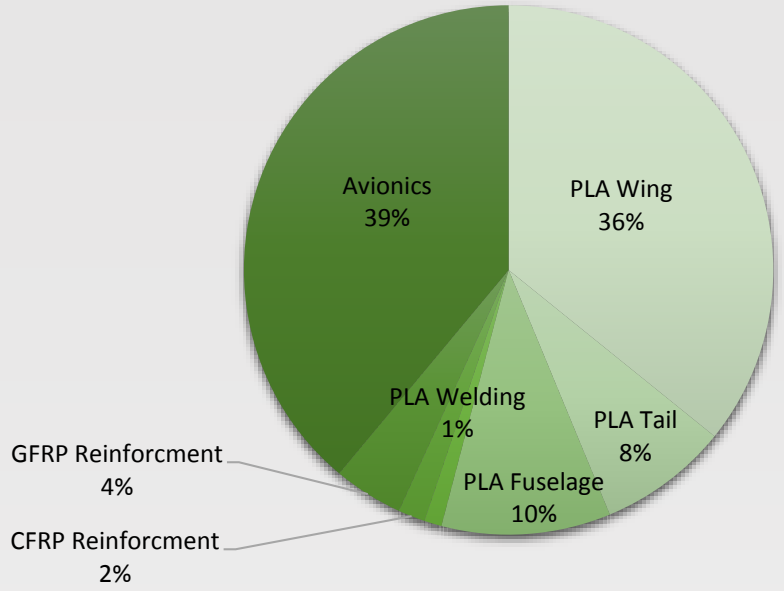
	Time	Cost	Weight
	h:m:s	€	g
WING	39:31:58	12,34	303,44
TAIL	12:40:27	2,74	67,28
FUSELAGE	22:16:34	3,56	87,58
TOTAL	**74:28:59**	**18,63**	**458,30**

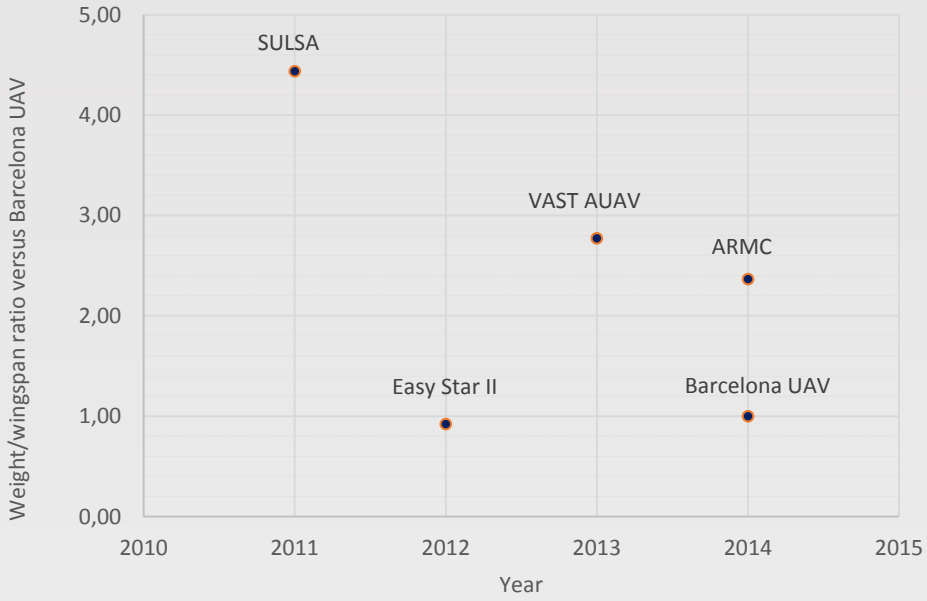




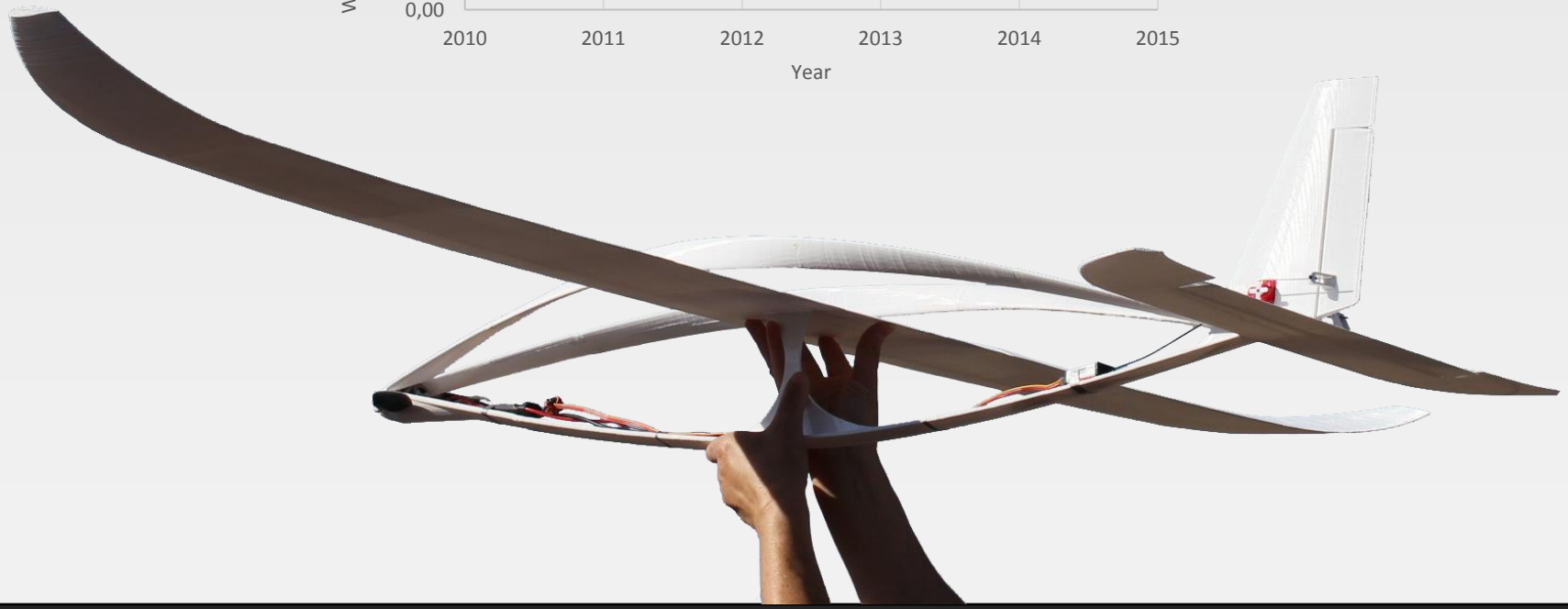
3D PRINTING	Material	3d printing	PLA Tensile test	Linear Model	Methodology	Result	Conclusions
BARCELONA UAV	Concept	Wing 3DP & UL tests	Tail	Fuselage	Assembly		

Model type	UAV
RMS	3D printing
Printer	RepRap BCN 3D+
Material	White PLA
Wingspan	1500 mm
Fuselage length	1135 mm
All-up weight	**845 g**
Wing area (wing + tailplane)	29,7 dm^2
Minimum wing load	28 g / dm^2
Autonomy (2000 mAh-4600 mAh ECO pack)	40-90 min
Range (2000 mAh-4600 mAh ECO pack)	30-70 Km
PLA Material & Manufacturing Energy Cost	18,63€





The lightest 3D printed UAV in the world



YouTube MakerBot Thingiverse Google+ Arevo

United States	24.0%
Spain	13.0%
Germany	6.7%
France	4.8%
United Kingdom	4.1%
Others	47.4%

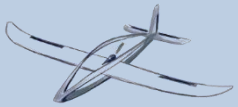
10k views
19k visits
1k beta-testers

3D PRINTING	Material	3d printing	PLA Tensile test	Linear Model	Methodology	Result	Conclusions
BARCELONA UAV	Concept	Wing 3DP & UL tests	Tail	Fuselage	Assembly		

NEW 3D PRINTED UAV **SUBJECT**

Escola Tècnica Superior d'Enginyeries Industrial i Aeronàutica de Terrassa

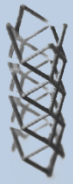
UNIVERSITAT POLITÈCNICA DE CATALUNYA



INTERNATIONAL

CAT UAV

3D PRINTED UAS EVENT



Centre Català del Plàstic

BARCELONA UAV

Is just the beginning

Specialized

New technology

International

GREATEST OPPORTUNITIES

The only limit is your imagination

No location

STL market

Low cost technology

NEXT STEPS

Conductive materials

Flexibility control

Lightweight infill

Welding method

Thank you for your attention and enjoy 3D printing

jonatandomenech@yahoo.es

Escola Tècnica Superior d'Enginyeries Industrial i Aeronàutica de Terrassa